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English Translation of the Amendments under PCT Article 34 as originally filed

generating means to a focus of the light collected by the first concave mirror respectively;

a distance between the reflection plane of the second concave mirror and the source of luminescence is shorter than the distance between the source of luminescence and the focus of the light collected by the first concave mirror;

a part of the reflection plane of the first concave mirror is formed around the reference axis; and

the second concave mirror is placed substantially outside luminous fluxes formed by having the light of the light generating means reflected on the first concave mirror.

The 2nd aspect of the present invention is a light source apparatus comprising:

light generating means;

a first concave mirror of collecting a part of light radiated from the light generating means; and

a second concave mirror of collecting another part of the light radiated from the light generating means not collected by the first concave mirror and reflecting it on the first concave mirror,

wherein a reflection plane of the first concave mirror and a reflection plane of the second concave mirror are in a form of non-rotation symmetry to a reference axis

connecting a source of luminescence of the light generating means to a focus of the light collected by the first concave mirror respectively;

a distance between the reflection plane of the second concave mirror and the source of luminescence is shorter than the distance between the source of luminescence and the focus of the light collected by the first concave mirror;

a part of the reflection plane of the first concave mirror is formed around the reference axis; and

the second concave mirror is placed in luminous fluxes formed by having the light of the light generating means reflected on the first concave mirror.

The 3rd aspect of the present invention is the light source apparatus according to the 1st or the 2nd aspect of the present invention, wherein the first concave mirror has one or a plurality of quadratic surfaces as the reflection plane.

The 4th aspect of the present invention is the light source apparatus according to the 3rd aspect of the present invention, wherein the quadratic surface of the first concave mirror is a part of an ellipsoidal surface, and one of the focuses of the ellipsoidal surface substantially coincides with the source of luminescence of the light generating means while the other coincides

with the focus of the light collected by the first concave mirror.

The 5th aspect of the present invention is the light source apparatus according to the 1st or the 2nd aspect of the present invention, wherein the second concave mirror has one or a plurality of quadratic surfaces as the reflection plane.

The 6th aspect of the present invention is the light source apparatus according to the 5th aspect of the present invention, wherein the quadratic surfaces of the second concave mirror are a part of a spherical surface and a center of the spherical surface substantially coincides with the source of luminescence of the light generating means.

The 7th aspect of the present invention is the light source apparatus according to the 1st aspect of the present invention, wherein the reflection plane of the first concave mirror is located closer to the source of luminescence than the reflection plane of the second concave mirror; and

the following relations are satisfied if, when a focusing angle of the first concave mirror is divided in two by a plane including the reference axis, a larger angle is α, a smaller angle is β, a maximum angle of the light radiated from the light generating means to the

first concave mirror and the second concave mirror is γ, and the focusing angle of the second concave mirror is θ:

(Formula 1)

$$\alpha > \beta > 0$$

(Formula 2)

$$\alpha + \beta \geq 180 \text{ degrees}$$

(Formula 3)

$$0 < \theta \leq \gamma - \beta.$$

The 8th aspect of the present invention is the light source apparatus according to the 2nd aspect of the present invention, wherein the reflection plane of the second concave mirror is located closer to the source of luminescence than the reflection plane of the first concave mirror; and

the following relations are satisfied if, when a focusing angle of the first concave mirror is divided in two by a plane including the reference axis, a larger angle is α, a smaller angle is β, a maximum angle of the light radiated from the light generating means to the first concave mirror and the second concave mirror is γ, and the focusing angle of the second concave mirror is θ:

(Formula 1)

$$\alpha > \beta > 0$$

(Formula 2)

$\alpha + \beta \geq 180$ degrees

(Formula 4)

$0 < \theta \leq 180$ degrees.

The 9th aspect of the present invention is the light source apparatus according to the 1st or the 2nd aspect of the present invention, wherein

the light generating means is a lamp having a vessel body of accommodating the source of luminescence;

the vessel body has a spherical vessel portion of transmitting radiation light from the source of luminescence and a pair of ends projecting from the spherical vessel portion; and

the pair of ends is provided around the reference axis.

The 10th aspect of the present invention is the light source apparatus according to the 9th aspect of the present invention, wherein the spherical vessel portion has a first opposed plane opposed to the reflection plane of the first concave mirror and a second opposed plane opposed to the reflection plane of the first concave mirror and the reflection plane of the second concave mirror; and

the part of the reflection plane of the first concave mirror is at least opposed to the second opposed plane.

The 11th aspect of the present invention is a lighting apparatus comprising:

the light source apparatus according to the 1st or the 2nd aspect of the present invention; and

lens means placed at a position optically connecting with the focus of the light collected by the first concave mirror of the light source apparatus and converting the light emitted from the light source apparatus substantially to parallel light.

The 12th aspect of the present invention is the lighting apparatus according to the 11th aspect of the present invention, wherein the lens means is a rod integrator.

The 13th aspect of the present invention is the lighting apparatus according to the 11th aspect of the present invention, wherein the lens means is a lens array.

The 14th aspect of the present invention is the lighting apparatus according to the 11th aspect of the present invention, wherein there are a plurality of the light source apparatuses placed so that the respective reference axes thereof coincide in the same plane; and

it further comprises light guiding means of guiding the light emitted from the plurality of light source apparatus to the lens means.

of the lamp light-emitting portion 111, and is reflected thereafter on the ellipsoidal mirror 12 so as to be focused on the second focus F2 of the ellipsoidal mirror 12 together with direct light from the lamp light-emitting portion 111.

Thus, the light source apparatus according to this embodiment has the configuration in which the ellipsoidal mirror 12 is in non-rotation symmetry to the optical axis 14, where the light directly radiated from the lamp 11 is reflected to form the luminous fluxes in non-rotation symmetry and the light radiated from the lamp 11 and not reflected on the ellipsoidal mirror 12 is reflected on the ellipsoidal mirror 12 again by the spherical mirror 13. Therefore, an amount of luminous fluxes close to the luminous fluxes in rotation symmetry is secured even in the case of the luminous fluxes in non-rotation symmetry.

Furthermore, the ellipsoidal mirror 12 is formed in non-rotation symmetry to the optical axis 14, and the reflection plane is formed to go round to the back of the lamp light-emitting portion 111 so as to directly collect the light from the same light transmission plane as that reflecting the light reflected on the spherical mirror 13. Thus, it is not necessary for the spherical mirror 13 to reflect all the radiation light from the light transmission plane 111a as with the light source

to obtain the maximum light collection efficiency. However, the size of the light source apparatus itself becomes larger because the radius of curvature of the spherical mirror 13 is fixed even if a focusing angle of the ellipsoidal mirror 12 is changed.

For that reason, according to this embodiment, it is possible, by rendering the radius of curvature R of the spherical mirror 13 shorter than the inter-focus distance L of the ellipsoidal mirror 12, to strike a balance between improvement in the light collection efficiency and miniaturization of the apparatus.

Next, a description will be given as to conditions of realizing the light source apparatus in non-rotation symmetry to the optical axis 14 having improved optical usable efficiency and in the form not enlarging the size of the spherical mirror 13.

Figures 6 and 7 show sectional views on a vertical plane at which the angle for the spherical mirror 13 to take in the radiation light from the lamp light-emitting portion 111 becomes the largest. To be more specific, the sectional views show the section at which the angle of viewing the spherical mirror 13 from the lamp light-emitting portion 111 becomes the largest.

The following holds in the case where, of the focusing angles of the ellipsoidal mirror 12 including the optical

axis 14 and divided in two at the plane orthogonal to the line A-A' of Figure 2, the larger one is angle α and the smaller one is angle β, and a maximum angle of the light radiated from the lamp 11 is γ, and the range of the focusing angle of the spherical mirror 13 is θ, and if the spherical mirror 13 is outside the reflected light of the ellipsoidal mirror 12 within the range scarcely blocking the light reflected on the ellipsoidal mirror 12 as shown in Figure 6, that is, if the reflection plane of the ellipsoidal mirror 12 is placed closer to the lamp light-emitting portion 111 than the reflection plane of the spherical mirror 13.

(Formula 1)

$\alpha > \beta > 0 \quad (1)$

(Formula 2)

$\alpha + \beta \geq 180$ degrees (2)

(Formula 3)

$0 < \theta \leq \gamma - \beta \quad (3)$

The reflection plane defined by the angle α reflects the radiation light from the light transmission plane 111b, and the reflection plane defined by the angle β reflects the light from the light transmission plane 111a.

It is desirable to satisfy the following in the case where the spherical mirror 13 is formed on a surface of the vessel portion of the lamp light-emitting portion

111 or in proximity thereto within the range scarcely blocking the light reflected on the ellipsoidal mirror 12 as shown in Figure 7, that is, in the case where the reflection plane of the spherical mirror 13 is placed closer to the lamp light-emitting portion 111 than the reflection plane of the ellipsoidal mirror 12.

(Formula 1)

$\alpha > \beta > 0$ (1)

(Formula 2)

$\alpha + \beta \geq 180$ degrees (4)

(Formula 4)

$0 < \theta \leq 180$ degrees (5)

As for the condition of Figure 6, it is radius of curvature R of the spherical mirror 13 < inter-focus distance L of the ellipsoidal mirror 12.

Here, an important point is that β is positive. This provides the configuration in which the reflection plane of the ellipsoidal mirror 12 is vertically astride the optical axis 14 on both sides thereof in Figures 6 and 7. Furthermore, it provides the configuration in which the reflection plane is opposed not only to the light transmission plane 111b but also to the light transmission plane 111a by straddling the end 111c of the lamp 11. Thus, the ellipsoidal mirror 12 is vertically astride the optical axis 14 on both sides thereof and the reflection

plane is opposed not only to the light transmission plane 111b but also to the light transmission plane 111a. It is thereby possible for the ellipsoidal mirror 12 to directly collect the light from the lamp light-emitting portion 111 at a large angle. The spherical mirror 13 can be small-size since it has only to collect a small amount of the remaining light which cannot be completely collected by the ellipsoidal mirror 12 out of the light from the light transmission plane 111a. Therefore, in this state, the light radiated from the lamp light-emitting portion 111 and heading for the ellipsoidal mirror 12 without suffering a loss to be focused on the second focus F2 becomes the largest. This involves a relatively small amount of light generating significant loss in the course of directly heading for the spherical mirror 13, getting reflected, passing through the vicinity of the lamp light-emitting portion 111 and heading for the ellipsoidal mirror 12 until getting reflected on the ellipsoidal mirror 12 where it is focused on the second focus. Thus, the light collection efficiency of the light emitted from the entire light source apparatus is improved in comparison with the conventional examples without substantially changing the size of the ellipsoidal mirror 12.

The formula (1) indicates the condition for the reflection plane of the ellipsoidal mirror 12 to be in non-rotation symmetry to the optical axis 14.

As shown in Figure 3, it is possible to place a light source apparatus 100, mirrors, a rod integrator 101 made of glass poles or mirrors glued together, and optical means 102 such as a lens of this embodiment at predetermined positions so as to obtain a lighting apparatus of this embodiment of converting the light emitted from the light source apparatus 100 to predetermined approximately parallel light.

As shown in Figure 4, it may also be the lighting apparatus using a lens array having multiple lenses two-dimensionally placed rather than the lighting apparatus using the rod integrator having the glass poles or mirrors glued together.

Furthermore, as shown in Figure 5, it is possible to additionally provide a field lens 104, a light modulation device 105 and a projection lens 106 to the lighting apparatus so as to obtain a projection display apparatus of this embodiment.

It is possible to use as the light modulation device 105 a reflective light valve, a transmissive light valve, a mirror panel capable of changing a direction of reflection with small mirrors placed like an array, and the light modulation device of an optical writing method.

Furthermore, while Figures 3, 4 and 5 show the lens as the optical means of converting the radiation light

from the light source apparatus 100 to illumination light, it may also be the optical means using the mirrors and a prism in addition to the lens or the optical system including an optical component combining multiple lenses.

Furthermore, while Figure 5 shows the configuration having just one transmissive light valve as the light modulation device, it may also be the configuration having multiple light modulation devices.

Furthermore, although it is not shown, it may be the configuration using the prism, filter and mirror capable of performing color separation and color composition.

As described above, according to the first embodiment, it is possible to have the lamp 11, ellipsoidal mirror 12 and spherical mirror 13 and place the spherical mirror at the position capable of collecting the light not collectable by the ellipsoidal mirror in the form of non-rotation symmetry to the optical axis so as to obtain the light source apparatus of high efficiency and small size.

Furthermore, it is possible, by having such a light source apparatus of high efficiency and small size, to render it brighter by using the lamp of the same power and allow the same brightness by using the lamp of lower power so as to provide the lighting apparatus and

projection display apparatus capable of holding down power consumption.

The above description used the ellipsoidal mirror 12 as the first concave mirror. However, it may be any reflecting surface mirror having a quadratic surface, where a reflecting surface mirror in the form combining a parabolic mirror and multiple ellipsoidal mirrors may also be used. Furthermore, the first concave mirror is not limited to the quadratic surface but may also be formed by multiple planes or curved surfaces, such as a Fresnel mirror.

Furthermore, the spherical mirror is used as the second concave mirror. However, it may be any reflecting surface mirror having a quadratic surface capable of efficiently reflecting lamp radiation light to the proximity of the lamp light-emitting portion, where the reflecting surface mirror in the form combining the ellipsoidal mirror and multiple spherical mirrors may also be used. Furthermore, as with the first concave mirror, it is not limited to the quadratic surface but may also be formed by multiple planes or curved surfaces, such as the Fresnel mirror.

(Second Embodiment)

Hereunder, a second embodiment of the present invention will be described by referring to the drawings.

the optical spots formed on an incident side opening 2a of the rod integrator 2 smaller.

In the case of placing multiple ellipsoidal mirrors having their inter-focus distance reduced while rendering the focusing angle larger, it is known that the most efficient placement is that in the state of having a part of the ellipsoidal mirrors physically interfering. As such a configuration, there is the configuration already known as shown in Figure 16, wherein a part of the concave mirror 1 of each light source apparatus is cut off in order to prevent the concave mirrors 1 of multiple light source apparatuses from physically interfering with one another. In this case, however, there is a problem that the light collection efficiency is lower in a cut-off portion of the concave mirrors 1.

To avoid this problem, there is a configuration, as shown in Figure 13, in which a pair of light source apparatuses is placed to have their reflection planes opposed to each other and there is a mirror 200 placed immediately anterior to the incident side opening 2a of the rod integrator 2 at an angle of guiding the luminous fluxes emitted from multiple light source apparatuses 1 to the incident side opening 2a of the rod integrator 2.

In the case of this configuration, there is no physical interference of the concave mirror 6 itself. If the mirror 200 is placed to reflect all the luminous fluxes emitted from the concave mirror 6 onto the rod integrator 2 side, however, there are the luminous fluxes not reflected on the incident side opening 2a due to the physical interference of the mirror 200 so that the concave mirror 6 is not substantially used in certain areas (indicated by dotted lines in Figure 13). In this case, the ellipsoidal mirror has no interfering portion, and so the light incident on a mirror interfering portion is not consequently used even though the ellipsoidal mirror in rotation symmetry to the optical axis can be placed.

Next, Figure 14 is a diagram showing the configuration of a multi-lamp optical system using the light source apparatus of a conventional configuration as in Figure 12 as the light source apparatus of the optical system of Figure 13. In this case, there are areas of the first concave mirror 6 not substantially used (indicated by the dotted lines in Figure 13) as with the concave mirror of Figure 13. There are the luminous fluxes further reflected on a second concave mirror 7 and then passing through the proximity of the light-emitting portion and getting incident on the area of the first concave mirror 6 not substantially used in addition to the luminous fluxes

In the lighting apparatus, each light source apparatus 100 is placed so that the optical axes 14 coincide in the same plane to be on the same line in Figure 8.

The light source apparatus 100 is placed to orient a smaller reflection plane of the ellipsoidal mirror 12 toward an unused part of the portion interfered with by the mirror 200 and have a spherical mirror 13 positioned in the unused part. The mirror 200 is equivalent to light guiding means of the present invention.

In the case of such a lighting apparatus, the radiation light from the lamp 11 incident on the spherical mirror 13 is returned to pass through the vicinity of the lamp light-emitting portion 111, and is emitted thereafter onto the mirror 200 side via the reflection plane of the ellipsoidal mirror 12 capable of being used by the mirror 200 and the rod integrator 101. Therefore, it becomes the luminous fluxes suffering no loss after the rod integrator 101 so as to improve the optical usable efficiency of the luminous fluxes emitted from the light source apparatus.

To be more specific, on a specific section of the light source apparatus 100 including a luminescence center (equivalent to the focal position F1) on which the angle of viewing the spherical mirror 13 from the luminescence center is substantially the largest, the

improved because of the ellipsoidal mirror 12 having the reflection plane formed in non-rotation symmetry to the optical axis 14 and astride the optical axis 14. Therefore, the radiation light from the lamp 11 unusable so far can be used so as to improve the optical usable efficiency as the lighting apparatus.

It is also possible, of the luminous fluxes emitted from the lamp light-emitting portion 111, to obtain a larger number of luminous fluxes by direct light collection with the ellipsoidal mirror 12 as the shortest path and collect the remaining luminous fluxes via the spherical mirror 13 so as to significantly improve the light collection efficiency.

It is also possible, as with the first embodiment, to render the radius of curvature R of the spherical mirror 13 shorter than the focal length L of the ellipsoidal mirror 12 and thereby reduce the size of the light source apparatus 100 itself so as to miniaturize the entire lighting apparatus.

If the spherical mirror 13 is miniaturized, the focal length L of the ellipsoidal mirror 12 can also be reduced. Therefore, it is possible to form a smaller optical spot for an incident side opening end 101a of the rod integrator 101 so as to improve the light collection efficiency from the rod integrator 101 onward.

Thus, according to this embodiment, it is possible to obtain the lighting apparatus capable of realizing both high optical usable efficiency and miniaturization.

Figure 8 shows the example in which the light source apparatus 100 is placed to orient a smaller reflection plane of the ellipsoidal mirror 12 toward an unused part of the portion interfered with by the mirror 200 and have a spherical mirror 13 positioned in the unused part. As shown in Figure 17, however, it is also feasible to place each light source apparatus 100 so as to reverse positional relation between the ellipsoidal mirror 12 and the spherical mirror 13. In this case, it is necessary, for the sake of preventing the interference of the mirror 200, to take a larger distance between the light source apparatus 100 and the rod integrator 101. There is an advantage, however, that it becomes easier to hold the spherical mirror 13 and place members such as an adjusting jig.

Figure 8 shows the lighting apparatus using the rod integrator 101 made of glass poles or mirrors glued together as an example. However, it may also be the lighting apparatus using the lens array 103 having multiple lenses two-dimensionally placed as shown in Figure 9.

spherical mirror at the position capable of collecting the light not collectable by the ellipsoidal mirror in the form of non-rotation symmetry to the optical axis so as to obtain the light source apparatus of high efficiency.

Furthermore, it is possible, by thus having the light source apparatus of high efficiency, to render it brighter by using the lamp of the same output and allow the same brightness by using the lamp of lower output so as to provide the projection display apparatus capable of holding down the power consumption.

(Third Embodiment)

Figure 18 shows the configuration of the lighting apparatus according to a third embodiment of the present invention. In Figure 18, the rod integrator 101, a relay lens 102 and the light modulation device 105 are the same as the conventional examples and the second embodiment. To be more specific, it has the configuration in which the light source apparatus according to the first embodiment is used as the light source apparatus of the lighting apparatus of the conventional example shown in Figure 11. In this case, the pair of light source apparatuses 100 is placed to have their spherical mirrors 13 opposed to each other, and the rod integrator 101 is placed at an intersection which is a point in space at

CLAIMS

1. (Amended) A light source apparatus comprising:

light generating means;

a first concave mirror of collecting a part of light radiated from the light generating means; and

a second concave mirror of collecting another part of the light radiated from the light generating means not collected by the first concave mirror and reflecting it on the first concave mirror,

wherein a reflection plane of the first concave mirror and a reflection plane of the second concave mirror are in a form of non-rotation symmetry to a reference axis connecting a source of luminescence of the light generating means to a focus of the light collected by the first concave mirror respectively;

a distance between the reflection plane of the second concave mirror and the source of luminescence is shorter than the distance between the source of luminescence and the focus of the light collected by the first concave mirror;

a part of the reflection plane of the first concave mirror is formed around the reference axis; and

the second concave mirror is placed substantially outside luminous fluxes formed by having the light of

the light generating means reflected on the first concave mirror.

2. (Amended) A light source apparatus comprising:

light generating means;

a first concave mirror of collecting a part of light radiated from the light generating means; and

a second concave mirror of collecting another part of the light radiated from the light generating means not collected by the first concave mirror and reflecting it on the first concave mirror,

wherein a reflection plane of the first concave mirror and a reflection plane of the second concave mirror are in a form of non-rotation symmetry to a reference axis connecting a source of luminescence of the light generating means to a focus of the light collected by the first concave mirror respectively;

a distance between the reflection plane of the second concave mirror and the source of luminescence is shorter than the distance between the source of luminescence and the focus of the light collected by the first concave mirror;

a part of the reflection plane of the first concave mirror is formed around the reference axis; and

the second concave mirror is placed in luminous fluxes formed by having the light of the light generating means reflected on the first concave mirror.

3. (Amended) The light source apparatus according to claim 1 or claim 2, wherein the first concave mirror has one or a plurality of quadratic surfaces as the reflection plane.

4. (Amended) The light source apparatus according to claim 3, wherein the quadratic surface of the first concave mirror is a part of an ellipsoidal surface, and one of the focuses of the ellipsoidal surface substantially coincides with the source of luminescence of the light generating means while the other coincides with the focus of the light collected by the first concave mirror.

5. (Amended) The light source apparatus according to claim 1 or claim 2, wherein the second concave mirror has one or a plurality of quadratic surfaces as the reflection plane.

6. (Amended) The light source apparatus according to claim 5, wherein the quadratic surfaces of the second

concave mirror are a part of a spherical surface and a center of the spherical surface substantially coincides with the source of luminescence of the light generating means.

7. (Amended) The light source apparatus according to claim 1, wherein the reflection plane of the first concave mirror is located closer to the source of luminescence than the reflection plane of the second concave mirror; and

the following relations are satisfied if, when a focusing angle of the first concave mirror is divided in two by a plane including the reference axis, a larger angle is α, a smaller angle is β, a maximum angle of the light radiated from the light generating means to the first concave mirror and the second concave mirror is γ, and the focusing angle of the second concave mirror is θ:

(Formula 1)

$$\alpha > \beta > 0$$

(Formula 2)

$$\alpha + \beta \geq 180 \text{ degrees}$$

(Formula 3)

$$0 < \theta \leq \gamma - \beta.$$

8. (Amended) The light source apparatus according to claim 2, wherein the reflection plane of the second concave mirror is located closer to the source of luminescence than the reflection plane of the first concave mirror; and

the following relations are satisfied if, when a focusing angle of the first concave mirror is divided in two by a plane including the reference axis, a larger angle is α, a smaller angle is β, a maximum angle of the light radiated from the light generating means to the first concave mirror and the second concave mirror is γ, and the focusing angle of the second concave mirror is θ:

(Formula 1)

$\alpha > \beta > 0$

(Formula 2)

$\alpha + \beta \geq 180$ degrees

(Formula 4)

$0 < \theta \leq 180$ degrees.

9. (Amended) The light source apparatus according to claim 1 or claim 2, wherein

the light generating means is a lamp having a vessel body of accommodating the source of luminescence;

the vessel body has a spherical vessel portion of transmitting radiation light from the source of luminescence and a pair of ends projecting from the spherical vessel portion; and

the pair of ends is provided around the reference axis.

10. The light source apparatus according to claim 9, wherein the spherical vessel portion has a first opposed plane opposed to the reflection plane of the first concave mirror and a second opposed plane opposed to the reflection plane of the first concave mirror and the reflection plane of the second concave mirror; and

the part of the reflection plane of the first concave mirror is at least opposed to the second opposed plane.

11. (Amended) A lighting apparatus comprising:

the light source apparatus according to claim 1 or claim 2; and

lens means placed at a position optically connecting with the focus of the light collected by the first concave mirror of the light source apparatus and converting the light emitted from the light source apparatus substantially to parallel light.

12. The lighting apparatus according to claim 11, wherein the lens means is a rod integrator.

13: The lighting apparatus according to claim 11, wherein the lens means is a lens array.

14. The lighting apparatus according to claim 11, wherein there are a plurality of the light source apparatuses